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The Hazards of Radiation

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LADIES AND GENTLEMEN, it is a very great honor for me to be with you today and it is a particularly great honor to be asked to give this lecture in memory of our good and very great friend, Dr. Ernest O. Lawrence. In his life he has done a great many remarkable things. He was a builder, and the influence of his work reached from the investigation of the nucleus to national defense and from there again, very significantly, to the health of all of us. When he developed the instrument for accelerating particles, a development in which he stands above everybody, he had in mind all along to use the new nuclear tools for the purposes of medicine. In the Radiation Laboratory isotopes have been produced at an early time and there were many years when the Radiation Laboratory was *the* source of isotopes for the whole world. Because of his initiative and enthusiasm we in this country have a very considerable headstart in nuclear medicine.

This is a headstart which we have used well. I shall mention two very obvious uses. One concerns our fight against the greatest remaining danger to human health: cancer. At least in certain stages some cancer cells are more sensitive to radiation than the rest of the body. Thus radioisotopes can be of help in the treatment of cancer. The other point is even more important. With the help of isotopes one can follow the particular way in which any element goes through the complicated maze of biological activity, and in this way we can have a detailed and instructive insight into biochemical processes.

In addition to these great fields that I have mentioned, Ernest had a deep interest in one thing. He saw that the scientific results concerning radiation have been misunderstood, and he tried to set the record straight. It is this topic which I want to discuss with you today.

We have all heard about radiation hazards. We all know that people are greatly worried about these hazards. This danger has been exaggerated. There is a story which many of you may have heard, but I will repeat it because it illustrates Ernest's interest in this particular point.

When the 37-inch cyclotron started to function in 1935 and when neutrons began to come out of this instrument, one of the very obvious questions was whether the effects of the neutrons will be similar to the effects of x-rays, gamma rays, electrons, alpha particles and other radiation. Because this question arose, Dr. John Lawrence and Dr. Paul Aebersold rigged up a little apparatus with a rat inside, which had to be jammed into a very narrow space in the cyclotron. The rat confined in this narrow space was supplied with air which came through a little tube. The cyclotron was turned on. It ran for two minutes; Ernest said we better stop, look and see. He stopped and looked and the poor rat was dead. This caused an enormous consternation because the rat did not get a really big dose. It appeared that the neutrons were much more dangerous than any other radia-

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tion. Well, it took a little time to find out the real story: the tube which supplied the blasts of air to the rat was closed during the test and the rat suffocated.

This, ladies and gentlemen, was the first of many alarms about radiation, and like the rest of the alarms, it had little foundation. Unlike some of the other alarms, however, it had an advantage. It made all the people in the Radiation Laboratory very conscious of the possible danger of radiation, and partly because of care and I should say partly because of good luck, there has been a really excellent record of radiation safety in the Radiation Laboratory.

Starting from these early observations an important conclusion developed: Nuclear radiation and radiation damage is a simple thing. The effect of radiation is to tear molecules apart. There is nothing particularly specific in this. Some types of radiation are two or three times more effective than some other radiation, but by and large any radiation acts in a similar way as long as it gets into touch with tissues. The main question is, how much energy is delivered and to which tissues. Of course, the overall action may appear quite different. You may have penetrating radiation which traverses the whole body, or soft radiation which stops in the skin. There can be radiation from isotopes which are deposited in certain organs, and only these organs will be irradiated. But as long as some tissue is irradiated, the effect of the radiation is reasonably accurately estimated, if not really measured, by the amount of radiation energy delivered to that tissue.

This is in exceedingly sharp contrast with the effects of chemical agents which have a key and lock property. A molecule in which you have made a little substitution can change from a food into a poison. And to predict, on the basis of chemical evidence, the biological effects is beyond our present knowledge and may remain so for some time. Therefore, to begin with, radiation is a much simpler agent. But I hope that you will not draw the conclusion from this that therefore its effects upon us are simple. While radiation is simple, we unfortunately are complicated. You do something to us, and God knows how we are going to react.

The topic which I first want to discuss and which I want to keep in the forefront for quite some time is the danger from the worldwide distribution of radiation—the worldwide fallout from nuclear tests. And this is the very point that some of us, very much including Ernest, have discussed frequently and carefully.

The scare about worldwide fallout is something about which we must have clear understanding, because it interacts with very specific medical problems. As you know, there has been quite a bit of controversy about nuclear fallout. Some people believe—maybe some of you believe—that this controversy has been in part caused by the circumstance that nuclear explosions, nuclear testing and the fallout that comes from nuclear testing has been secret and therefore the general public, even physicians like you, did not have an opportunity to be fully informed. This statement is only partially right. In fact, in the main it is just plain wrong. Information about distribution of nuclear contamination has been kept secret prior to 1953. In the year immediately preceding 1955 all of this information was available to the public. Suspicion did continue that some facts are held back. This is not true. The record is public and the record is complete. Then after the record was complete, radioactivity was dragged into the political arena in the election of 1956.

Let me try to tell you how some propagandists who try to scare the people summarize their argument. Their summary is effective, it is simple, and it has the appearance of fact. The summary goes like this. We know that the exceedingly small doses of radiation which the worldwide distribution of fallout will give to the individual has a very small chance to harm an individual, one chance in 100,000, or perhaps one chance in a million. But there are very many people in the world, and if there is one chance in a million then 3,000 people will be hurt, and if there is one chance in 100,000, 30,000 people will be hurt. We should not hurt thousands of people.

This argument, while it sounds simple and plausible, is wrong. Fallout has so small an effect that nobody ever has observed it. And nobody knows either from direct observation, or from statistics, or from any valid theory whether the claimed damages in fact exist or do not exist. I want to talk about that a lot more, because talking about the effects of various doses of radiation leads us immediately into an interesting field of research which should be important for all of us. The plain fact is that we do not know what are the effects of small doses of radiation.

At this point the oponents of testing argue: "All right, we do not know whether this radiation is dangerous or not. Therefore, wouldn't you think that as long as we do not know whether it is dangerous or not we should abstain from spreading such radiation around?" This again sounds like an eminently reasonable argument, and I would say there is a little bit of truth in it, but only a little bit. There is considerable evidence that the real effects are very considerably smaller than the effects which I have mentioned. I believe that exceedingly few people have been actually harmed by fallout, possibly the opposite may have been the case. Radiation might have beneficial effects.

Before we continue this argument I want to put before you some simple facts. *Fact Number One* I have already put before you: essentially all radiation acts in a similar way. How it will act in very small doses we do not know. But we know that small doses of neutrons, small doses of x-rays, of gamma rays, of beta rays, of alpha rays, and of cosmic radiation will all act very similarly. We know this from physical evidence; we know it from chemical evidence; we know it from a concurrence of a great deal of biological information.

Fact Number Two is this: For more than one hundred million years, ever since fish took the courage to emerge from the ocean, all of our living ancestors have been exposed to cosmic rays. And even those of our ancestors who were sheltered by many feet of sea water drank radioactive potassium and other materials; even those were not exempt from radioactivity. The natural background of radiation to which we and our ancestors have been exposed is approximately fifty times as great as the radiation which we get from all the fallout about which you have heard so much. In addition, we are exposing ourselves for good reason to medical x-rays.

Let us consider first only diagnostic x-rays and not the much discussed therapeutic doses. These diagnostic x-rays which an average healthy individual gets in his life amount to about as much as the natural background. Therefore, the amount of radiation that the average individual is getting is one hundred times as great as the fallout which we are getting. More than that, natural radiation changes from place to place a great deal. You are courageous people for having come up here to Colorado. Do you realize that you are 7,000 feet closer to the sky, that there is less air between you and the heavens, and the cosmic radiation, which is much stronger than fallout, is beating on you with a much greater intensity than any you could expect from fallout even where fallout is concentrated. I do not know how many of you are as foolhardy as I am to carry a radioactive wrist watch which is hardly visible to your eyes if you try to look at it at night, but nevertheless sends a Geiger counter into frantic activity. The natural background about which we usually do not hear, about which we usually do not worry is greater and its changes from one place to another are greater than anything you can expect from fallout. This natural background will be different if you are higher up. It will be different and greater if you live in a brick house. It will be different if you change your diet. It will be different if you live in a part of the country where there is a little bit more thorium or uranium in the ground. All the prophets of doom are silent about these dangers which are much greater than the dangers about which they preach.

Could it conceivably be that, knowingly or not, these people are worrying about something else than radiation when they talk about fallout. I understand, gentlemen, that we here are modest people, interested in nuclear medicine and not in psychiatry or politics. Therefore, this last question I will have to leave unanswered.

I would like to make an appeal to you. A few years ago there has been introduced a concept which seems useful—the maximum permissible exposure of a person. I say that this concept seems useful. I also say that this concept is most disturbing, misleading, dangerous, and that you should get rid of it. We do not know what the effects of small irradiations are. Therefore we cannot tell what is the maximum permissible exposure. And since most of the people who make such decisions are conservative, they set the maximum permissible exposure as low as possible so as to be really safe. Probably ten or one hundred times the permissible dose will not cause damage either. Yet, figures are published and then somebody finds out: "I've had 20 per cent of the maximum permissible exposure. I have gone 20 per cent towards some kind of a disaster which I do not understand, but which quite possibly is as bad as getting cancer." The alarm that has been spread by this word, "maximum permissible exposure," has been tremendous. And then the experts get frightened and lower the maximum permissible exposure by a factor 2, and then everybody says: "When will they lower it again? Perhaps I already have the maximum permissible exposure."

Recently better words have been introduced. Instead of "maximum permissible exposure" we should use the "Radiation Exposure Guide," a guide which will be different when you expose the whole population, different and higher for professions, different, still higher in emergency situations where some chances have to be taken. It is also complicated, and I would advocate that we don't talk too much in public about this guide.

I would advocate that we should talk in public about one thing only. We should agree on the average background exposure. Assume the average background exposure is one-tenth of an "r" per year. Let us agree on a firm figure and then let us tell people. The maximum permissible dose is a figment of man's imagination. The average background comes from God, and furthermore since everybody is exposed to it, is a much more reasonable and democratic unit. It is also much more reassuring.

The public has been scared into an unreasonable behavior. Those of you who have the information must talk not only to their own patients but to the public and must counteract the unreasonable and unscientific fear mongers.

I would now like to talk to you about some more interesting questions concerning fallout. What is probably the real danger? It has been estimated by many that due to fallout the lives of some 20,000 or 50,000 people might be shortened. All of this has been based on a very simple hypothesis. And because it is simple, therefore it is plausible. And because it is plausible it is widely used. And because it is widely used it is widely believed. Yet, the connection between this hypothesis and truth is exceedingly tenuous.

The hypothesis is that if one thousand "r" units do a certain damage or do damage with a certain probability, then one "r" unit will cause the same damage with one-thousandth that probability. This statement is based on the single-hit theory, that is, the idea that if one molecule is disrupted, the disruption of this one molecule is irremediable and will produce an ultimate consequence with a fixed probability.

Examples of the opposite abound. We know that something like five hundred "r" units delivered in one dose will kill half the people if they are healthy, and more if they are not. Yet, we know that we can in fractionated amounts deliver one thousand or two thousand "r" units without any danger of short-time injury, although some clear-cut danger of long-range development of some disastrous diseases exists. Proportionality between the dosage and effect is certainly not demonstrated. In fact, there is no good statistical evidence of any damage to the individual, unless that individual got approximately one hundred "r" units. At the same time, if he gets five hundred "r" units in one dose, he has a 50 per cent chance of dying. Therefore the full range in which proportionality between cause and effect can be explored is only a range of five-fold change in radiation. In this range the experiments are complicated and conflicting; some of the evidence clearly contradicts proportionality; other evidence seems to show proportionality but in an unclear manner. The evidence is derived from laboratory experiments, from irradiated populations in Hiroshima and Nagasaki, and it comes from therapeutic applications or radiation. The upshot of these results is that no clear-cut evidence is obtained for proportionality in any pathogenic effect.

There have been animal experiments with low-level irradiation. Even this low-level radiation is one hundred times as great as the fallout, and there are essentially no experiments with as low a level as the fallout. The low-level irradiations have been carried out by Dr. Lorenz in the National Institute of Health, Dr. Carlson at Washington State. There are some indications that when you expose mice and rats to these low-level radiations, these animals live 10 per cent longer. Many people say the evidence is incomplete, and I must add on my own—they look incomplete to me. I don't know whether the evidence is conclusive. The simple fact is that when you get to very low levels of irradiation you do not know whether the effect is proportional to the first power of the radiation, whether it is proportional to a high power of radiation, whether it has a threshold so that below that threshold there is no damage or whether below a certain threshold there even are beneficial effects.

Radioactive waters used to be advertised as beneficial. This claim was unscientific. But the opposite claim that all radioactivity is harmful is not much more scientific either. We simply do not know.

I believe that some effects are proportional but probably only a very few, because most processes in our bodies are likely to be more complicated and are not due to one single event. The very idea that cancer could be caused by one single event flies in the face of general experience like precancerous stages, which shows that cancer develops in several stages rather than being due to one single cause.

Now I would like to mention to you another field about which we have been fully as much disturbed —the genetic effects of radiation. In the genetic effects the situation is different. Very detailed studies have shown that irradiation of the spermatozoa of fruit flies gives rise to mutations strictly proportional to the dose, and therefore proportionality has been demonstrated in a wide range between twenty-five "r" units and four thousand "r" units. I think this is good, solid, scientific work. But the results are different for the spermatogonia and for the Oocytes. If you have a bare cell nucleus which is stripped down to the genetic apparatus and contains nothing else, like the spermatozoa, then indeed the effects are simply proportional to radiation, and the single-hit theory seems to be supported. If you deal with spermatogonia, the situation is more complicated. Then you deal with a cell nucleus and a cell body and the effects of radiation depend on the dose rate. The effect becomes smaller if instead of a single dose you fractionate your dose. Repair mechanisms seem to become possible, and only strong irradiation in one dose is really damaging. The same seems to hold for the female cells, for the ovum. In worldwide fallout the dose rate is small. Spermatogonia and oozoa may not be damaged at all.

We have heard that fallout produces a terrific genetic burden. To begin with, radiation from fallout is only 1 per cent of the radiation which we are getting anyway. Secondly, I do not think that all mutations are harmful. All mutations of course are abnormal because only what is not mutated is what we call normal; and as every reasonable group of individuals we believe that we are the peak of creation. But really to believe this, not emotionally, but intellectually, would seem to deny the simple fact of evolution. You must allow that something that is new might be better.

Mutations are increased by fallout, but probably by less than 1 per cent. Many mutations in us are probably due to the spermatogonia and oozoa. In these, fallout probably produces practically no effect. Furthermore, some very excellent Swedish research men have pointed out that mutations are caused because we are foolish enough to wear trousers. This causes a temperature change in one of our organs; this will lead to a mutation rate surpassing the effects of fallout more than hundredfold. The Swedish geneticists therefore recommended that the prophets of genetic doom should wear kilts.

There is, ladies and gentlemen, one little point which I would like to make in all seriousness. There can be very little doubt that the modern medical art can keep people alive who otherwise would die. This increases the number of surviving mutations. For instance, a person who has diabetes can live longer and have children. This probably increases the genetic burden much more than fallout. In a humanitarian sense it is obviously correct to save lives. Furthermore, I do not think that this is necessarily a disadvantage from the point of view of the evolution of the race. Why do we have mutations? Due to mutations we can adapt ourselves. Can you think of an age which changes more rapidly than ours? Can you think of an age where adaptation is more necessary than it is in ours? By allowing more mutants to survive we allow more adaptation. Perhaps those among us who have diabetes and who can now be kept alive have a linked property of being temperamentally more suited to live peacefully with their neighbors. Perhaps they are on the average more intelligent. Nobody knows. I think that the expression, "genetic burden," is ill chosen.

Fallout is not dangerous. But the fallout scare is. Many people know that a medical x-ray gives you one hundred times as great a dose as fallout will give you in your whole life-time. How many people have been scared away from x-rays? How many people have gone with their ailments unrecognized and untreated, only because there has been this needless and exaggerated fallout scare? I don't know. I don't know whether anybody has been killed by fallout, but I am sure that many have been killed by the fallout scare.

There are many cases in which people were frightened away from the much more massive therapeutical doses. A year ago my sister had trouble with her thyroid. The tissue had to be removed either by an operation or by the iodine treatment. You all know that the operation has some small hazards. You know also that radioactive iodine treatment is simple, painless and safe. My mother, who is a great worrier, almost prevented the iodine treatment, and it took all my eloquence to put it through. I wonder how many are the cases in which people have abstained from needed radiation treatment because of the fallout scare. There must be many, many such cases.

It is not unusual that in a serious case of cancer, a surgeon will undertake an operation, which is dangerous. He will tell the patient that there is a chance that he will die during or immediately after the operation, and in such a serious operation it is not at all unusual to accept a hazard, of let us say 20 per cent. As far as I know, in the case of radiation treatment no hazard is ever accepted. If there is a hazard of death we abstain from the treatment. I do not see any logical or sensible reason for this distinction. Either the procedure of the surgeon is too radical or else our procedure with radiation is too conservative. Perhaps our conservatism at present can be defended on the basis that in many cases we may not yet know enough. But in principle there must not be any difference between the two. Radiation damage is considered today as something unknown, new, dreadful, something that has to be avoided under all circumstances. I think this is unrealistic, and I think that this lack of realism has cost many people their lives.

This lack of realism can be removed only by very thorough public education. The problem of explaining radiation hazards is essentially the same whether you explain the practically nonexistent hazard of fallout, whether you explain the hardly more existent hazard of diagnostic x-rays, or whether you are talking about therapeutic x-rays or irradiations which are necessarily hazardous. In all three cases public education is essential, and public education can be undertaken by no one as effectively as by you.

I know that Ernest Lawrence would not want me to conclude my talk without emphasizing some positive aspects of nuclear medicine. We are finding out more about the effects of radiation. This will result in more faith in the use of radiation. It will result and it should result in a wider application of radiation for therapeutic purposes, as a diagnostic tool, and particularly as a research tool.

There are two great killers left. One, the degenerative circulatory diseases; the other cancer. In both of these cases the research that is needed in order to bring help is research which can be done much better with the help of radioactive isotopes than in any other way. With the help of radioactive isotopes you might be able to follow the slow growth, the slow deposition of unwanted substances on the walls of an artery or the slow changes in any other organ. With the help of radioactive isotopes you can find what chemicals will go to this or that cell, to a healthy cell or to a cancerous cell. In this way we might be able to get closer to a meaningful chemotherapy of cancer, whether this be chemotherapy using chemicals that we synthesize or whether it be chemicals of a more complicated kind, which are called antigens. It is even possible that the miracle of the cure of thyroid cancer can be repeated, that we can incorporate radioactive isotopes into some molecules which will seek out the cancer cells even after they have been distributed all over the body, and in this way get rid of a cancerous condition in a stage in which no other method is likely to help.

We have so far used in our radioactive research a relatively small number of radioactive isotopes, namely, those which live long enough so that they can be made and then distributed and then used at leisure. There are many more radioactive isotopes of a short life. Using these you could open up the whole periodic system for the purpose of research and for the purpose of therapeutic irradiation. You might be able to inject a radioactive isotope in a very specific location and before the isotope had much of a chance to migrate away from the location it would have decayed. Of course, if you want to use these isotopes you have to have the source of these isotopes readily available. Fortunately, the sources of isotopes have become very much cheaper. I hope that nuclear reactors might appear in all medical research centers, perhaps in all hospitals. You can inject the activated substance seconds after it has left the reactor and in this way you might be able to use for your research, diagnostic or therapeutic work isotopes which have as short a lifetime as a minute or two. We need these isotopes to unravel biochemistry and to get even closer to this mysterious complication which we call life.

Ernest had a very unusual ability of taking pleasure in progress, quite independently of whether he or someone else made that progress. I hope that this spirit will prevail among us. Only by taking pleasure in our mutual achievements, only by going ahead with confidence and courage, will it be possible to master the enormously complicated field of biochemistry, the science of life.

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